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Learning Analytics @ UC3M

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***Abstract*:** Feedback is important for any activity, and learning is no exception. Whereas assessment can give summative feedback about the proficiency of the learning, learning analytics can give a much finer level of feedback about the learning process. Learning analytics can help in identifying the effectiveness of learning elements, can help in engaging students, can guide teachers in the preparation and deployment of the teaching activity. In this paper, we present a number of different initiatives carried out at UC3M that include elements of learning analytics for different purposes.

Keywords: e-learning, technology-enhanced learning, learning analytics, virtualization, gamification, visualization

I. Learning Analytics

"Information is the oil of the 21st century, and analytics is the combustion engine," says Peter Sondergaard, senior vice president at Gartner [1], in order to emphasize the importance of analysing information to get useful knowledge. In [2] we can read a good definition of the term analytics and its application in the educational context: "Analytics is the use of data, statistical and quantitative methods, and explanatory and predictive models to allow organizations and individuals to gain insights into and act on complex issues. In colleges and universities, analytics is used to improve operational efficiency and student success."

Learning analytics is the formal, documented, computer-processed equivalent of the informal impression a teacher can have about the learning performance of a student. It can be of benefit to all the stakeholders: to students, who can better identify their strengths and weaknesses, to teachers, to assess the situation of their class, to the developer of study programmes, or the pedagogists, in order to identify best learning practices. Learning analytics is also a key aspect in the new wave of learning digitalization promoted by MOOCs (Massive Open Online Courses), where direct teacher-student interaction is not possible because of the scale.

In this paper we present several initiatives carried out at UC3M that harness the power of analytical tools in a number of different ways. Here are the headlines of the initiatives in order of increasing abstraction:

- First, events relevant to the learning process need to be captured. All kinds of detailed events can be captured if students are given a virtual machine to study and to develop projects. We present the setting deployed for this purpose with the CCOLAB system.
- Visualizations are a mechanism often used to present analytics information in a graphical way. We present LearnGlass, an extendable system to create visualizations of learning information.
- Analytics can especially help in online learning. The Khan Academy provides a platform with a rich analytics component. We have used this platform for remedial courses of Physics with success in the context of the Genghis project.
- Analytics information can also be used to help orchestrating face-to-face classes. The ClassOn system is presented.
- Analytics information can also be processed automatically and conveyed to the student in terms of a gamification-oriented output in order to engage the student. One particular use consists of setting up competitions among students. The ISCARE system is presented.

II. Capturing Learning Events in Virtual Machines

One of the issues that appear when deploying learning analytic applications is the trade-off between the level of detail for the observations, and user privacy. In principle, a comprehensive observation of student behavior is desired, but a too invasive technique may provoke user rejection and achieve the opposite effect of obtaining a poor set of observations. Privacy may be considered as a currency. Students and instructors are offered some additional functionality at the expense of their events being recorded. In this context, the objective then is to deploy an observation paradigm that is *affordable* from the point of view of user privacy.

Learning scenarios offer a rich setting to explore this trade-off. In general, a learning experience is restricted to a set of users with certain common interests (the topic of the experience) that interact among themselves, with the instructors and a set of resources over a fixed amount of time. These ingredients are heavily influenced by the topic of the experience. A comprehensive observation of the events related to the course, and only those, offers a promising balance between privacy and exhaustive observation. In other words, a detailed observation of student interactions while they participate in an experience but *only* in this context would be more likely to be accepted as a reasonable cost in terms of privacy by the students.

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Virtualization is a technique that consists on simulating an entire computer system using a second system. The simulated machine is called a *virtual appliance* to differentiate it from the *physical machine* that is actually executing the simulation. This technology has been present since the time when the first computers appeared, but it was not until performance of conventional equipment has reached certain point when these appliances begun to be widely used for portability tests, scaling complex systems, etc.

Virtualization in education has been scarcely used in very particular environments. Those experiences that require computers with highly specialized software tools tend to adopt virtualization to provide an affordable replica of this configuration to each student. Virtual appliances are also used in those courses in which students need to practice administrative tasks in a system without running the risk of damaging real infrastructure.

Today's personal computers have enough computing power to execute a virtual appliance as any other regular application in a user desktop space. The proposed approach requires the creation of a virtual appliance fully configured to carry out all the activities corresponding to a learning experience. There is a wide variety of companies offering both commercial and free solutions for this type of usage. The virtual appliance needs to be created either by the instructors or technical staff and its appearance configured to adapt to the specific course content. Once the virtual appliance is created, it is exported and prepared for distribution. Students then are instructed to first install the virtualization software and then to download the file containing the appliance and install it in their personal computers.

As a result of this procedure, all students have a system identically configured, with parameters all known to the instructors, and coexisting with the rest of applications in their personal computers. The appliance is then included in all the course documents as *the platform* through which all the work related to the course should be carried out. The appliance has its own file system, which should contain the files produced during the course, a browser, communication applications such as chat, etc. Since the appliance will only be used for the course, there are several special features that can be easily included. For example, the browser may include a set of bookmarks for quick access to the course material, or to quickly post a comment in the course forum. Additional special features could include preloaded course notes, tools, manuals, etc.

Aside from this specific configuration, the appliance can include also a tracking mechanism by which a subset of the events occurring while executing any of its applications is recorded and relayed back to a central server. If the transmission of these events is done through an authenticated connection, the events are received and labeled as belonging to a user [3].

This approach has been used in a pilot experience in a second year course on telecommunication engineering about C programming. Students need to participate in a large number of activities involving certain tools. Proficiency in the use of such tools is one of the learning outcomes in the course. A virtual machine was prepared with all these tools installed and configured to be used during the semester. Additional customizations were included such as a quick menu in the browser to access the virtual community supporting the course, the forum, the course notes, etc. The appliance is downloaded after students agree to its terms of use. This document describes the events that are being recorded, what is the use of such data, and how can they disable the tracking mechanism should they decide to do so. They are also notified that they may exercise their right to access and delete the collected data at any point in time to comply with current privacy regulations.

The events recorded in the appliance include: commands type at the command line interface, execution of the C compiler, execution of the C debugger, execution of a memory profiler, pages accessed through the browser, and the commands to interact with a version control system (Subversion).

After two editions of the course, the level of adoption of these appliances is nearly 80%. In its second edition a data set consisting of nearly 500,000 events was collected [4].

Virtual appliances offer an interesting middle ground between activities that must be totally self-contained in corporate learning management systems, and activities that are carried out in personal computers with no possibility of observation. The data obtained from the described experience can be used to detect levels of student engagement, team dynamics, work patterns, and even the assessment of learning outcomes such as the proficient use of certain tools.

III. VISUALIZATIONS WITH THE LEARNGLASS SYSTEM

The life cycle of a learning analytics process includes three stages. First, data generated within the learning activities is collected and processed. The second stage consists of analysing and summarizing the data in order to infer meaningful information. At the last stage, the inferred information is used to provoke an intervention that would improve the learning activity for both learners and instructors. The cycle finishes and starts over so the intervention outcomes can also be analysed and evaluated.

One of the approaches to provoke interventions in a learning activity is by showing visualizations to both instructors and learners. Visualizations are a common mechanism used to reflect information that would be difficult to understand with textual descriptions or tabulated numbers. In this case, visualizations reflect the information that has been inferred from the analysing the data of the learning activity.

Visualizations for learning environments often present many specific requirements that are not related to the visualization but to the context where it will be displayed. Examples of these requirements are management of users and permissions, and management of data-sources.

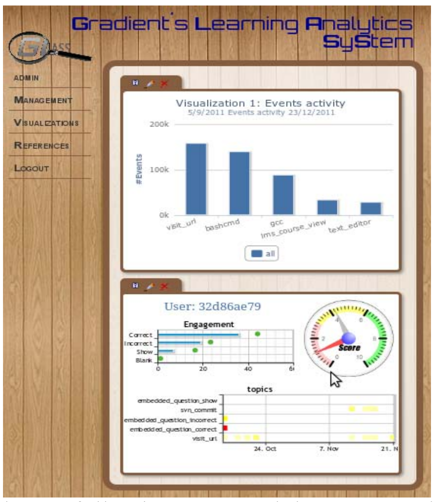
As a solution to ease the process to develop visualizations for learning scenarios, we have developed LearnGlass [5], a web platform that allows the deployment of visualizations with a common data source of learning events. It provides management of users' permissions and management of data sources; it also provides the implementation of a filters and dashboard.

In the permission management section, the user is able to assign to each user a role among *administrator*, *instructor*, *student* and *observer*. Each role has a defined set of privileges such as modifying users, changing permissions, installing new modules, adding data sources, and seeing data of other users. The user can also grant or revoke the privileges of each role. Basic tasks related to user management are delegated to a LDAP service. Thus, actions like adding, modifying and removing a user are done from any application to manage LDAP directories.

Filters allow the user to select the specific subset of data to include in the visualization. When an administrator adds a new data-source, the system analyzes the events stored in it and suggests meta-data that can be meaningful filters. It also tries to identify the type of filter to use, being either an open value input or a finite value selector. For example, a common event meta-data to use as a filter is the user identifier. Thus, the system decides whether to ask directly the user for a given user identifier or to show a list for the user to select, depending on the amount of users stored.

The dashboard is the welcoming page for every user and it displays a set of visualizations previously selected and configured by the user. A sample of what the dashboard looks like is shown in Figure 1. The layout of the dashboard follows a grid pattern and the number of columns for the grid can be between 1 and 6, defined by an administrator. The visualizations in the dashboard are already configured, this is, the user apply a set of filters defined by the user and adds the resulting visualization to the dashboard. There is no limit on the amount of these snapshots of visualizations for the user to add to her dashboard.

Figure 1. LearnGlass dashboard showing two visualizations



LearnGlass, following a modular approach, can be extended through the installation of modules. A module must include the visualization that will be displayed to the user; this view may include an interface to change the filter settings of the visualization. Optionally, the module may provide a light version of the visualization is one to be embedded into a user dashboard. The purpose of having two visualization views is that the full view allows a high degree of interaction with the user, while the light view is meant to provide a quick overview of the visualization. Currently, two modules have been developed as extensions of LearnGlass: the first one is an activity reporting module that presents bar charts or line charts of the amount of events generated by learners (shown at the top in figure 1). The second module displays the portraits of the learners that generated the most events and the learners who generated the least.

Current work on the system includes the evaluation of its usefulness for learners and teachers during the enactment of a learning activity. Another line of future work is the implementation of additional modules to be used in specific learning scenarios, such as learning within a specific domain or following a teaching methodology in particular. The visualization mockup at the bottom of figure 1 is an example of a module addressing the methodology of active learning.

IV. The Genghis Project: Remedial Courses with Khan-style Teaching Support

The use of technological systems that retrieve detailed data about students' events and interactions when doing typical learning activities is increasing. Several online learning platforms can collect different types of data about the learning process, and present it to students and instructors. The Khan Academy platform[1] is one of the best platforms that provide a powerful learning analytics module. This module does not only provide directly collected data, but also generates useful high-level information as a result of a processing of low-level data.

The Khan Academy platform allows making a set of learning videos available, where students can also post comments. Furthermore, exercises can be designed according to the defined HTML framework[2]. These exercises present a nice interface and students can make different attempts, request hints, or watch related videos. The exercises are parametric, so that each time a student accesses them, she will receive the same exercise with different parameter values. Exercises are grouped into skills. A student has to solve a sequence of exercises correctly in a row in order to obtain proficiency in a skill. In addition, gamification techniques are implemented. Students can earn energy points by doing some actions. Moreover, students can obtain badges if they overcome different challenges or make certain actions on the platform. Some of the challenges are directly related to obtain proficiency in a set of skills. Other functionality is the possibility for students of defining their own learning goals or customization options.

Learning analytics in the Khan Academy platform plays an important role. The commented functionality generates many students' interactions and many different low-level data is collected (e.g. the specific materials that are accessed by students, the requested hints, their access time instants, or the order of the different actions). This low-level information can be processed to infer interesting high-level information that can be useful for the learning process.

[1] http://www.khanacademy.org/
[2] https://github.com/Khan/khan-exercises

The Genghis project at Universidad Carlos III de Madrid [5] aims at flipping the classroom using a local instance of the Khan Academy platform. In the first phase, which took place in year 2012, the project has been successfully applied for a 0-course in Physics with more than 100 registered students. 0-Courses are remedial courses for first year students with difficulties in math and basic science. The key idea of flipping the classroom is that students can watch videos and practice exercises before the face-to-face classroom sessions, and then use the classroom sessions to ask questions and go further into details. With this objective, teachers prepared a collection of videos and exercises about Physics. Students had to work on these materials on August 2012. Then in September, students received the regular class sessions.

Our local instance of the Khan Academy platform was personalized according to the needs of the university (e.g. styles of web pages or set of badges that students can obtain). The project was a complete success and many students' interactions were retrieved.

In this experiment for the 0-course of Physics, teachers, instructors and other stakeholders can obtain a strong benefit from the learning analytics information generated by the Khan Academy platform. In addition, we have increased the potentiality of the Khan Academy platform, adding an extension of their learning analytics module. We have processed low-level data and converted them into high-level information.

Here we give a list of some of the available learning analytics information retrieved in the initial Genghis experiment and offered by the Khan Academy platform by default:

- A list of the state of each one of the different skills for each student. The state can be "started", "reviewing", "struggling" or "proficiency". This gives an idea of the types of exercises that a student tried, and where she had problems.
- Progress summary: For each skill, the number of students that are in each one of the different states. It is the same information as before but presented by skills instead of by students. This gives an idea of the types of exercises where students had more problems or that need to be redesigned.
- Activity report for each day. This visualization gives information about the students that interacted with the platform divided by days, the time that they interacted, the videos they watched, or the skills they addressed.
- Skill progress over time. This plot presents the days (axis X) and the number of skills achieved until that day (axis Y). From it the total number of skill proficiencies that each student obtained can be inferred, but also that there were students that worked during all the time period, while others only worked for a few days.
- Evolution of the activity. For each student, her activity in the platform for each day: time watching videos, time solving exercises, energy points, or badges earned.
- Focus: The percentage distribution of each student activity in the different topics.
- Badges earned. The badges earned for each student: their types and the number of times a badge was earned (in cases where earning a badge more than once makes sense).
- Detailed information with exercises. Information about each student interaction with an exercise: the instants of times where she attempted the exercise, her input answers, her requested hints, if previously watched the related videos, etc.

Although interesting information is generated by default by the Khan Academy platform, other new high-level information can be inferred that can be of interest for stakeholders. For this reason, we have extended the Khan Academy learning analytics module, and have calculated extra relevant information for the 0-course in Physics. Some examples of this high-level information provided by our own learning analytics extension module are the following:

- Total time of use of the platform. This information gives insights about the total time that each user spent on the platform (for videos, exercises and both) or a global percentage of the total possible use, taking into account a weight related to the importance of each topic, the percentage of each video that the user watched (with respect to the total time of each video) and the exercises that the student really attempted out of the total. In addition, activity in other extra functionality (students' goals or customization) is given. All of this information is important in order to know the total use of the platform and their distribution for each student from different points of view without taking into account how well she behaves on the platform.
- Correct progress on the platform. Parameters are calculated and shown to provide e.g. a percentage of videos where the student completed them for at least some percentage of time (weighted by the importance of the topics), a percentage of the skills where a student obtained proficiency or at least solved correctly one exercise (weighted also by the importance of the topics), or a percentage combination of both. These percentages can be given taking into account all the videos and skills or only the ones that students accessed. In addition, efficiency parameters are provided to denote not only if a student did it but the number of repetitions for achieving the proficiency or the number of times that a video was repeated. With all of this, it is possible to know how well a student did in the platform, i.e. the percentage of videos that were watched enough time, the percentage of skill proficiencies, or the efficiency when achieving the different goals.

- Time distribution. This information focuses on classifying students depending on the usual times they worked (morning, evening or night) or if students worked in a constant way or only on a few days.
- Gamification habits. This information permits to know if a student is motivated with the achievement of the proposed badges and her actions are oriented to obtain these badges, or if students are only interacting for solving exercises without taking care of the badges. This is important in order to know which students are more receptive to gamification techniques.
- Exercise solving habits. Among the presented information items for each student are: the level of hint abuse, hint avoidance, video evasion or reflection. It is interesting to identify those students with bad habits in their learning process.

All of these data provides teachers with useful information that can help them to infer the learning causes of different facts and make proper decisions to improve the learning process. In this way, teachers can act based on these reports. In addition, this information permits the definition of different learning styles for each student in many cases. This can be used e.g. for automatic recommendation purposes.

It is also important to note that each specific environment only allows a limited number of information items that can be inferred because of the environmental setup and restrictions. For example, our local Khan Academy environment does not allow retrieving some of the type of players as known from the literature because the game-basis semantics does not include data to deduce this information. For each environment, experts should do an analysis of the information that can be inferred. In addition, there is usually an uncertainty in the prediction of the information. The prediction is based on a set of reasonable causes and assumptions of the registered events, but the probability to have other causes for these facts is not always 0. For example, we can conclude a student to be a hint abuser, because we estimated based on her actions that she already knew the topics and should not use the hints, but maybe she had some problems with the exercises that required requesting for hints.

Finally, another important challenge is to find how to visualize the information so that it can be easily interpreted by teachers and other stakeholders. Initial visualizations have been carried out for the extended learning analytics module, but we are trying to improve them.

V. Just-in-time Teaching with the ClassOn System

One of the main affordances of learning analytics is to reveal hidden information. During the teaching-learning process, there are some parameters that students and teachers cannot be aware of, simply because they are not directly attainable. Learning analytics comes to the rescue providing teachers and students with these hidden parameters, for instance, in the form of data visualizations [6]. Data visualizations can be used to better understand the teaching-learning process in order to make the appropriate decisions. From the point of view of the teacher, she could make use of the data provided by analytics in order to plan and execute interventions, as part of the learning orchestration.

In this section of the article, we focus on providing hidden information to the teachers in a particular setting: face-to-face learning activities in a computer lab. In this setting, the teacher has to receive the information just in time in order to make the most appropriate interventions (just-in-time teaching).

The technical degrees offered by Universidad Carlos III de Madrid have a strong practical component. Hence, the vast majority of these courses include practical activities face-to-face in the computer lab. In order to support the just-in-time teaching needed in theses courses, the classON system [7] was developed. classON[3] (in-Class Live Analytics for aSSessment and orchestratiON) is a system aimed at supporting teachers in face-to-face activities in the computer lab. Based on learning events captured during the students' activity, it provides the teacher with information to a) regulate, enhance, and optimize teacher-student interactions; and b) improve learning orchestration, during the session (in class) and after the session (for a posteriori analysis).

The classON system architecture comprises several components:

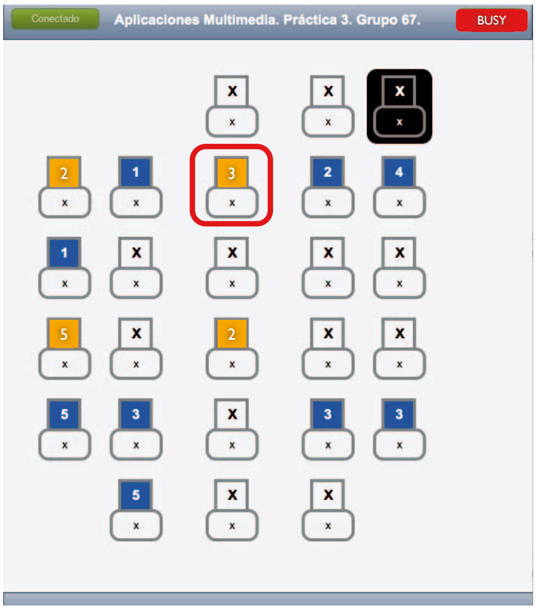
- A **student component**, integrated in the web-based problem statement delivered to the students; its main objective is to monitor relevant events in the students' activity and inform them to the server.
- A **teacher mobile application,** designed for tablet devices, which provides her with the information needed to regulate interactions in class. It also monitors teacher interactions with students and informs the server.
- A **server component**, built over technologies that enable just-in-time communication among the other components, such as *websockets* and *node.js*. It processes the events collected in the student and teacher components and sends the information to the teacher mobile app. It is also in charge of persisting the collected data and interactions.

The student component collects students' learning events such as progression in the assignment and questions that the students need the teacher to answer. The server collects these data, processes them, attaches them to the physical space of the computer room and makes them persistent. This information is sent to the teacher mobile application that presents her with an interface shown in Figure 2. The interface represents the physical space of the computer room augmented with information about the students' learning events. The icons in the interface represent the students working on the computer, and provide information about the progression of the students (number in the center of the icon) and the questions asked to the teacher. The color code of the icons indicates that the students are waiting for help (orange) or that they are simply working on the assignment (blue). The red square around an icon indicates the student that has been waiting longer. Given this augmented map, the teacher has enough information to

[3] http://www.class-on.org

decide what intervention is more convenient given the current situation. Besides, the teacher interface provides a detailed view of a student (triggered when touching the icon corresponding to the student) that shows the picture of the student, her name and the question she is waiting the teacher to explain. Hence the teacher is aware of the question beforehand, which can also contribute to a more efficient intervention.

Figure 2. Interface of the teacher mobile application in classON



The classON system has been put into practice in a Multimedia Applications course at the Universidad Carlos III de Madrid with successful results as presented in [7]. There are several future works related to the system:

- Creating appropriate data visualizations of the events and interactions of the face-to-face activity, for the teacher to review the session afterwards.
- Building a just-in-time set of frequently asked questions (FAQ) that the students can consult during the learning activity and find the answer to their questions to the teacher. Students will contribute to the system voting up useful questions.
- Defining a gamification system based on events and interactions that could make the activities more engaging for students.

VI. Promoting Student Engagement with Gamification and Competitions

The correct use of game elements for education produces an increase of students' motivation and an improvement of the learning process. In an educational game, it is also important to apply learning analytics techniques to track the students' learning progress and be aware of their activities. The use of computer-based systems for gamification enables a natural way of retrieving data and processing them in order to provide useful learning analytics information. In addition to information that can be typically used in other platforms, learning analytics that is specifically related to game elements is also important, e.g. to know which type of players the students are.

Several platforms with gamification elements have been developed at Universidad Carlos III de Madrid. One example is the ISCARE system [8][9] that allows competitions among students. The ISCARE tool permits the management of tournaments for their creation, listing or starting. Each tournament includes different rounds. In each round, students compete against each other in pairs, and each student receives a set of exercises that can be corrected automatically by the system. Each student can obtain tournament points for her scoring depending on the result with respect to her opponent, but also depending on the number of exercises that are solved correctly out of the total given in that round. The pairings are assigned adaptively with an artificial intelligence algorithm so that students with a similar scoring are assigned to compete. In addition, the assigned exercises for each pair are also adaptive so that students receive exercises with a difficulty level according to their current scoring in the tournament. The ISCARE system shows the results for each round, as well as leaderboards and the students' ratings for each round and after the tournament.

Two experiments have been carried out at Universidad Carlos III de Madrid with the ISCARE system in the years 2011 and 2012 in a Computer Architecture Laboratory course, a course of the second semester in the fourth year of a Telecommunications Engineering degree. This course is mainly practical with a distribution of 0.5 credits of theory and 2.5 of practical assignments. The topics of the course include shell script, makefile, FAT file system, and system calls.

Students played five and four rounds respectively (years 2011 and 2012), receiving different exercises per round. The exercises covered theoretical but also practical issues of all the topics of the course. The interaction with the ISCARE system took place at the end of the course, once all the theoretical materials have been taught by teachers and all practical assignments have been done by students. In these two experiments, pairings were assigned adaptively but the exercises were not personalized according to the students' level. Students interacted with the platform and rich information was generated by the learning analytics functionality:

- The evolution of the points for each different student over the different rounds, as well as her evolution in the order of the leaderboard over the different rounds. This gives insights about the progress of the students over a tournament, and the partial and final order with respect to their classmates.
- The total performance in a tournament. The final ratings give insights about the students' total knowledge in the topics of a tournament.
- The difficulty of the opponents a student had to compete against. This information is given by the sum of all the points that obtained all the opponents of a student in a tournament. This permits to check if a

student competed against other opponents with a high knowledge level or not.

- Information about each user. This provides information about the exercises that were assigned to a student, and the ones that were solved correctly or incorrectly. This permits to detect topics where a student has lacks.
- Information about the exercises. This provides insights about the total number of times that an exercise was presented to students, the number of times that was correctly and incorrectly solved. This is useful to detect the topics where students had more difficulties in the classroom or exercises that were not correctly designed and need to be modified.

Some improvements of the learning analytics functionality of the ISCARE system would be very useful and it can be an interesting future work. First of all, different profiles can be detected in the competition system related to the game elements: e.g. students that started with a low performance but finished with strong performance or the contrary or more constant students in their performance; fast players when solving exercises or slow players.

In addition, at present, there is information for each student about her points for each round, divided by points related to the performance on exercises and points related to the comparison with her opponent. But there is not a summary of global total points in a tournament in which only the points for solving exercises are reflected. This would be useful to know the performance of the student with exercises directly without taking into account the competition points.

Another possible improvement would be to analyze and present in more detail all the information related to the students' interactions when solving exercises: the instants of times when each student solves the different exercises in each round, correlation of players answers times with respect to their opponents (as both are watching the evolution of their opponents in real time), time strategies when answering, timeouts, etc.

Furthermore, the implementation of more powerful visualizations would be nice to improve how the information is represented. In this direction, for example, the inclusion of nice graphics about students' progress over time can be considered.

VII. CONCLUSION

As has been shown in the above examples and many more available in the literature, analytic techniques really make a difference in education. When one starts using these techniques, one wonders how it has been possible to teach before without them, so as to say in the blind. Occasional assessment certainly helps in knowing the learning status of your class, but the information provided by learning analytics techniques is much richer, and therefore can help making teaching much more effective. Nevertheless, much more needs to be researched and experimented, in particular, on what events to capture, how to process them, how to visualize them, how to relate them directly to learning outcomes, … This is an emerging field with lots of future promise.

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